Brought to you by **KARL**
US Army Research Laboratory
White Sands Missile Range, NM

Produced by
Barb Sauter

Directed by
Teizi Henmi

TEASER:

Coming up soon

REALITY-BASED NOWCASTING: THE UTAH WINTER EPISODE

This exciting new show on KARL will track the success of two teams attempting to make accurate weather predictions, under potentially confusing and difficult situations. Watch the *Forecasters* pit their mathematical strength against the **Nowcasters'** use of real observations to discover temperature, humidity, and wind values over the challenging terrain in northern Utah. You won't want to miss a single installment as we follow the contestants through December, January, and February trials.

SERIES PREMIER: *The Setup*

In early December, 2002, the producer came up with the ground rules, while the casting director selected two teams with the desired qualifications. Here's what we'll be watching over the next several exciting installments.

THE PLAYERS:
* The *Forecasters*
  - Hailing from Penn State/NCAR, the Forecasters use the MM5 model
* The **Nowcasters**
  - The Nowcasters use successive corrections to the MM5 model output, based on the observations from up to 18 surface stations

THE LOCATION AND SCHEDULE:
* Northern Utah (with slight incursions into adjacent areas in ID & WY)
  - A 420 km x 420 km area encompassing an urban area, the Salt Lake, mountains, and valleys, with terrain varying from 1240 to 3370 m
* December 2002 - February 2003
  - 50 days including 8 in Dec, 18 in Jan, and 24 in Feb

THE GOAL:
* Accurately predict surface weather parameters at approximately 50-60 sites with observations available through the Utah MesoWest cooperative
  - Parameters include temperature, dew-point temperature (or relative humidity), u- and v-wind components (or wind speed and direction)

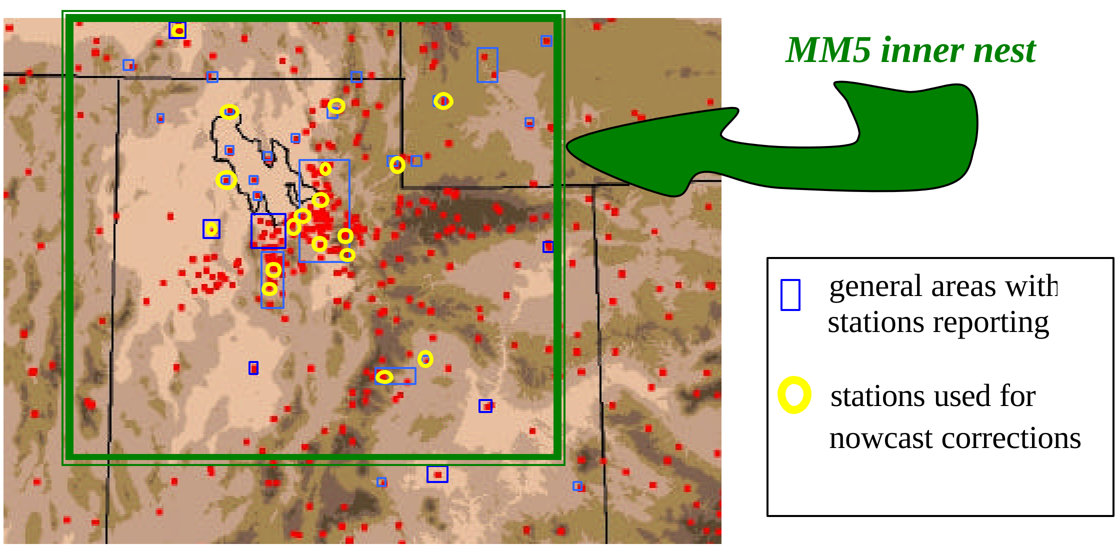
Setup Details

Each MM5 model run was initialized with 30 hours of GFS model output data, with the initial 18Z through 00Z as spin-up time prior to the validation times. The MM5 was then run in 3 nests on the Army High Performance Computing Resource Center's Cray computer:

- ✓ outer nest: 55 x 55 grid points at 45 km grid point spacing (2430 x 2430 km domain)
- ✓ middle nest: 55 x 55 grid points at 15 km grid point spacing (810 x 810 km domain)
- ✓ inner nest: 85 x 85 grid points at 5 km grid point spacing (420 x 420 km domain)

Hourly output from the inner nest was saved each day for 01Z through 00Z, equating to 6 p.m. through 5 p.m. the following day local Utah time.

The area of the inner nest is shown by the green square on the first graphic. The red dots indicate locations registered by the Utah MesoWest cooperative as having surface observing stations, but many of the locations do not report the required data on the hour to be used for these evaluations. The smaller blue rectangles indicate areas with appropriate stations reporting in early December.



Based on the availability of data, 18 stations were chosen to be used as input for the nowcast, as shown by the yellow circles on the map. These stations were selected primarily randomly, although with some consideration for covering the regions of interest and reflecting the diversity of the terrain.

MM5 forecasts of temperature, dew-point temperature, and u- and v-wind components at the grid points are bilinearly interpolated to the surface station locations. Well over 100 different stations within the MM5 domain reported observations on some of the various days covered. Typically, however, approximately 15 of the input stations and 50-60 other stations would be available at a forecast time. The nowcast uses the hourly observations from all the available input stations to perform successive corrections to the MM5 forecasts at all the remaining stations' locations. Each nowcast time is valid at the same time as the input observations.

The model and forecast runs were performed beginning mid December 2002 through February 2003, for days when the GFS model and the surface observations were available. During this period, a total of 50 days were used, including 8 in December, 18 in January, and 24 in February. Overall statistics were generated for the entire winter period, as well as for each month separately. In addition, in order to highlight specific cases, the 16th of each month was randomly chosen for a daily analysis of the forecast and nowcast performance. The following installments will focus on some of these results.

INSTALLMENT 1: *Day 1*

The *Forecasters* and the **Nowcasters** each handle the very first day of the contest like old pros, in spite of unsettled early winter weather. Behind the scenes, we see the following conditions on the set:

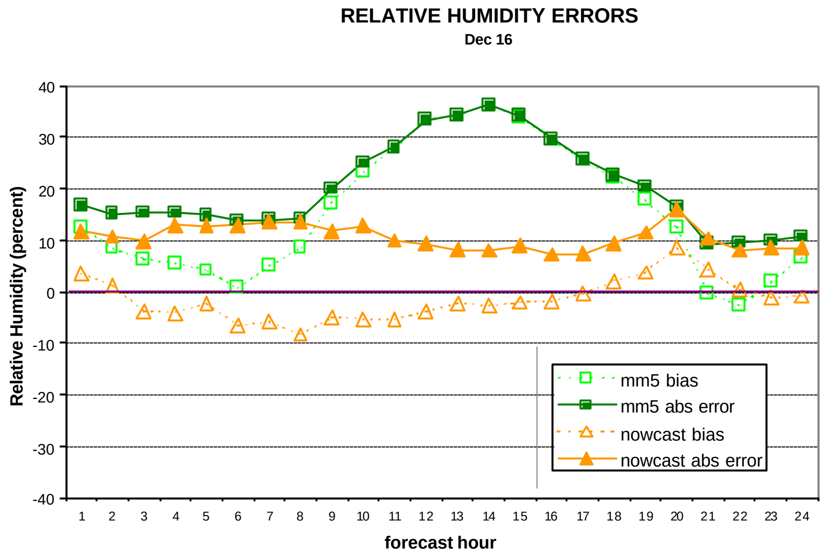
- ✓ Winds are primarily light to moderate from the southwest at hour 1, on the evening of December 15. The flow becomes more southerly through the day on the 16th in advance of a trough. An increasing number of stations report wind speeds of 5-10 m/s with several stations experiencing 10-15 m/s surface winds.
- ✓ Temperatures consistently range from approximately -10 °C at the highest elevations throughout the 24 hours, to maximum values over the diurnal period of 5 - 10 °C. A fairly large 5 °C standard deviation persists over the forecast hours for the 48-63 stations reporting each hour, including those used as nowcast input stations.

The input stations available for the **Nowcasters** included 10-16 station observations each hour. The input station in Idaho never appeared on day 1, with this record repeated frequently throughout the series. The input stations to the north and west of Salt Lake did not report wind values on many of the hourly reports. However, since there were not many validation stations in these areas, these omissions are not considered a significant factor in the **Nowcasters'** performance. The number of validation stations reporting varied from 32 to 47 over the 24 hours, which is fewer than will be dealt with on most subsequent days.

Day 1 Highlights

The *Forecasters* started out on day 1 with a significant warm bias, primarily due to missing the coldest temperatures at the very high elevations as well as the cold drainage into some valley locations in the early morning hours. The **Nowcasters** were able to minimize bias, beating the *Forecasters'* mean difference of 1.3 °C with a mean difference close to zero. They sometimes overcorrected, however, resulting in an absolute difference improvement of 0.4 °C.

Relative humidity errors were generally within 10-15 % for both *Forecasters* and **Nowcasters**, except that the *Forecasters* missed the relative humidity by 25-35 % in the morning hours. The **Nowcasters** were able to correct those values, keeping the errors near 10 %, as shown in the graphic to the right.



The contest to determine wind conditions ended up close to a tie on day 1. Both teams exhibited the ability to pin wind speeds to within 3 m/s and wind directions to within 40 degrees during most forecast hours. The *Forecasters* over estimated the wind speed more often than under estimating it. Once again, the **Nowcasters** showed less of this bias, but displayed several hours with positive and several hours with negative biases.

INSTALLMENT 2: *December Recap*

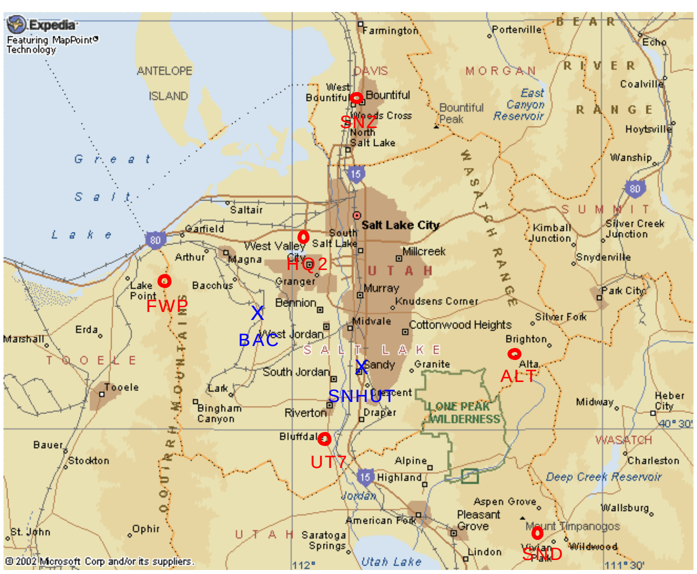
Only 8 days are included in the December totals. The *Forecasters'* absolute errors become slightly larger as the forecast hours increase for temperature, relative humidity, and wind speed. The **Nowcasters'** absolute errors of temperature and relative humidity are somewhat lower and remain more constant through the forecast hours. Their wind speed errors are also slightly lower, but do grow in later forecast hours. The wind direction errors do not reflect any pattern associated with the forecast hour. The **Nowcasters** performed worse than the *Forecasters* for the majority of hours for wind direction.

The following table provides the scores for the month of December.

		Forecasters	**Nowcasters**	ADVANTAGE *month 1*
TEMP °C	*mean error*	1.0	-0.2	**Nowcasters** *by 0.8*
	abs error	2.1	1.8	**Nowcasters** *by 0.3*
RH %	*mean error*	1.7	-1.3	**Nowcasters** *by 0.4*
	abs error	13.7	10.1	**Nowcasters** *by 3.6*
WIND SPEED (m/s)	*mean error*	0.9	-0.2	**Nowcasters** *by 0.7*
	abs error	2.3	2.0	**Nowcasters** *by 0.3*
WIND DIR (deg)	*abs error*	42.0	43.9	*Forecasters* *by 1.9*

INSTALLMENT 3: *Day 20*

Welcome to day 20 of the *Forecasters* vs. the **Nowcasters**. We'll investigate the performance on January 16, and see how one of the input stations is voted off the set. This installment will focus on the results at two validation stations in the vicinity of Salt Lake City, as shown as BAC and SNHUT on the map below.



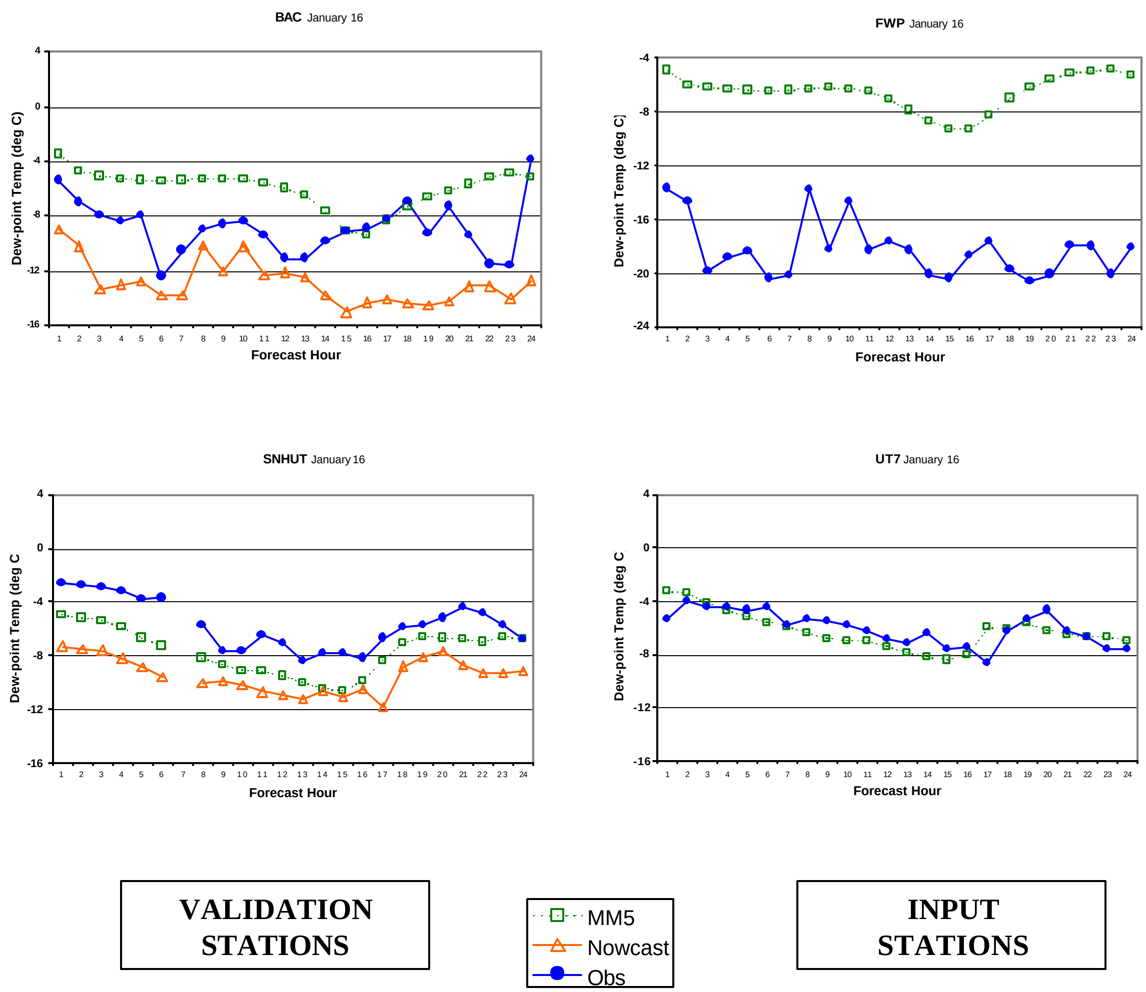
X Validation Stations (other validation stations exist in the area but are not shown on this map)

O Input Stations

In the initial nowcast trials, the temperature and dew-point temperature results were totally unrealistic. One of the surface stations used as input was reporting observed temperature and dew-point temperatures over 150 °C. The **Nowcasters** had not been given rules to ignore values outside possible ranges, and blindly “corrected” the validation stations to similarly hot and humid conditions never seen in nature. After fixing this oversight, the affected nowcasts were recomputed. The input station HQ2 was not used for this day and many subsequent days as it continued to report observations outside the allowable range.

Day 20 Highlights

These graphs show the dew-point temperature results for specific sites after removing the bad station.



Notice that the upper and lower numbers of the scale for input station FWP at the upper right contain lower dew-point temperature values (-24 to -4), but the total range and relative amounts of 4 °C per line remain consistent with the other charts (-16 to 4).

The *Forecasters* cannot reasonably predict the significant hourly jumps in the observed dew-point temperatures shown for some of the hours. Three of the stations show the model results generally too warm for BAC, too cold for SNHUT, and close to just right for UT7. At the same time, the *Forecasters* put the dew-point temperatures significantly higher than reported by the station in the mountains, FWP.

The **Nowcasters** obviously relied on the observation vs. forecast values at FWP in coming up with their BAC nowcast. This served them well enough for most of the times from forecast hours 6 through 13, as well as hours 22 and 23, when the forecast errors were most similar to those at FWP. However, they overcorrected slightly at these times, and overcorrected significantly at other times, leading to much greater errors at hours 16-18, when the forecast had been right on. SNHUT is further away from FWP, so its influence was moderated but still the probable cause for the **Nowcasters** to be led astray in taking forecast values that were too cold and generating nowcast values that are even colder. Since UT7 did not share this underprediction seen at SNHUT, it was not particularly useful in providing corrections. The largest error at UT7 occurred at hour 17, and the nowcast does seem to have used that information to erroneously lower the value at SNHUT even more.

INSTALLMENT 4: *January Recap*

January totals include 18 days. The *Forecasters'* temperature errors include a strong warm bias in hours 1 through 15, with the associated absolute errors growing from 2.5 °C to 3.5 °C over these hours. As the warm bias decreases through the daytime hours, the absolute errors are reduced to 2.0 °C. The **Nowcasters'** temperature errors remain consistent throughout the 24-hour period, with minimal bias and absolute errors close to 2.0 °C. The most pronounced diurnal variation in relative humidity errors is associated with the forecast bias of too low humidity during the night and too high humidity during the day. The nowcast bias is consistently toward too low relative humidities. Wind speed errors include very little diurnal variation, but do reflect a slight bias to be too high at night for both the forecast and the nowcast. As in December, the January wind direction errors show seemingly random but not particularly significant jumps from hour to hour, although as may be expected the wind direction errors are typically less during daytime hours than at night, when more variable conditions often occur. The **Nowcasters'** absolute errors are less than the *Forecasters'* absolute errors at every hour for temperature, relative humidity, and wind speed. Wind direction is the one parameter the **Nowcasters** can't seem to win, showing an improvement over the forecast in only 3 of the 24 hours.

The following table provides the scores for the month of January.

		Forecasters	Nowcasters	ADVANTAGE *month 2*
TEMP °C	*mean error*	2.0	-0.1	**Nowcasters** *by 1.9*
	abs error	2.9	2.0	**Nowcasters** *by 0.9*
RH %	*mean error*	-1.6	-3.9	Forecasters *by 2.3*
	abs error	16.6	14.1	**Nowcasters** *by 2.5*
WIND SPEED (m/s)	*mean error*	0.2	0.1	**Nowcasters** *by 0.1*
	abs error	1.6	1.5	**Nowcasters** *by 0.1*
WIND DIR (deg)	*abs error*	54.4	57.4	Forecasters *by 3.0*

INSTALLMENT 5: *Day 40*

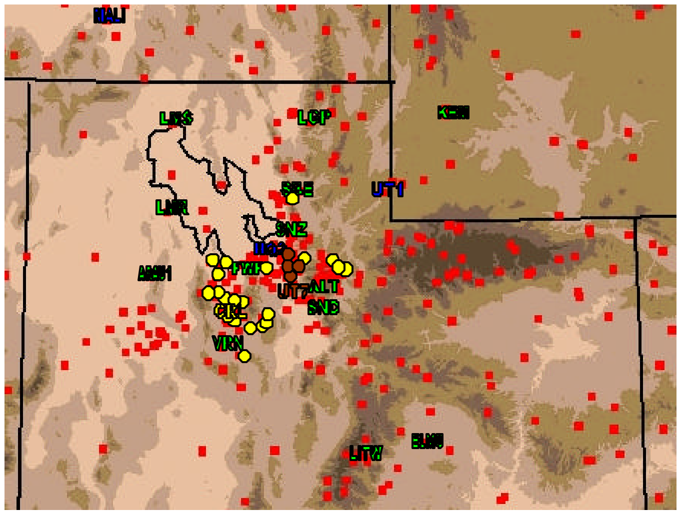
Day 40 of our contest takes place on February 16. An initial look at the results by forecast hour showed a spike in temperature errors at hour 17 for both the Forecasters and the **Nowcasters**. Of course, the rules of the game say that observations are accurate, but we saw on day 20 that in reality some observations are bad. The **Nowcasters** can call on friends in the input stations to decide how to modify the forecast values at the validation stations, but they follow the friends' potentially differing advice based on how close and loud the friend is. This particular installment reveals that some friends' advice should be viewed with great skepticism.

Day 40 Highlights

Taking a close look at the Hour 17 temperature results, they can be categorized into three groups:

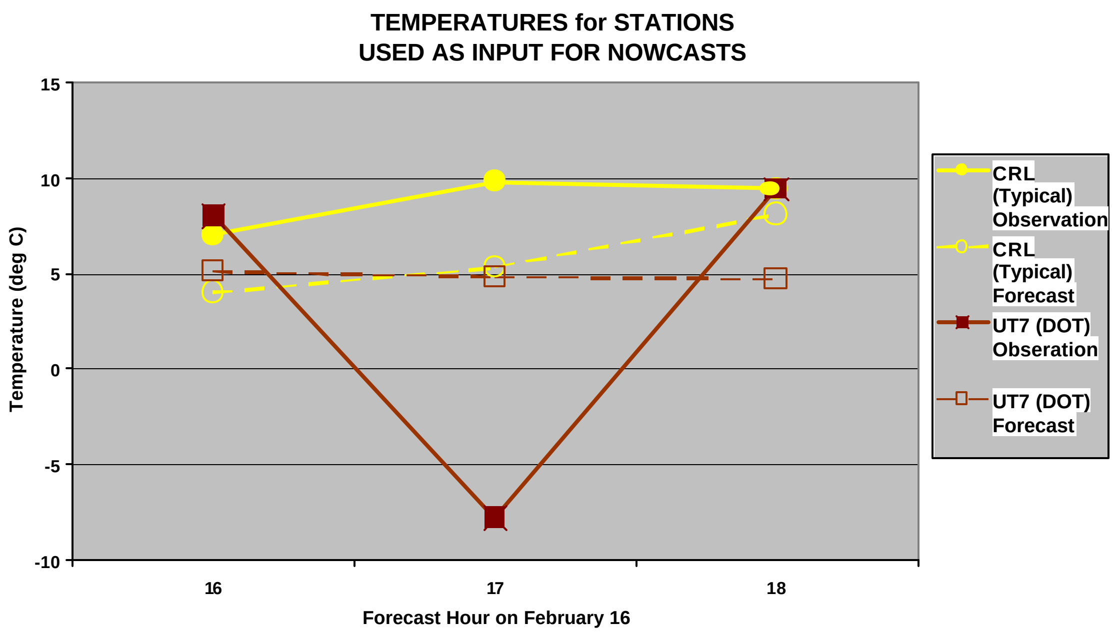
- ✓ Stations not displaying an unusually large error increase
- ✓ Stations warming faster than expected in the morning, resulting in generally accurate Hour 16 and Hour 18 temperature forecasts, but Hour 17 (10 a.m. local) temperatures under forecast
- ✓ Stations reporting an absurdly large decrease in observed temperature at Hour 17

This map shows the locations of validation stations reflecting the "typical" under forecast error of the second group in ye llow. Locations of stations (Utah Department of



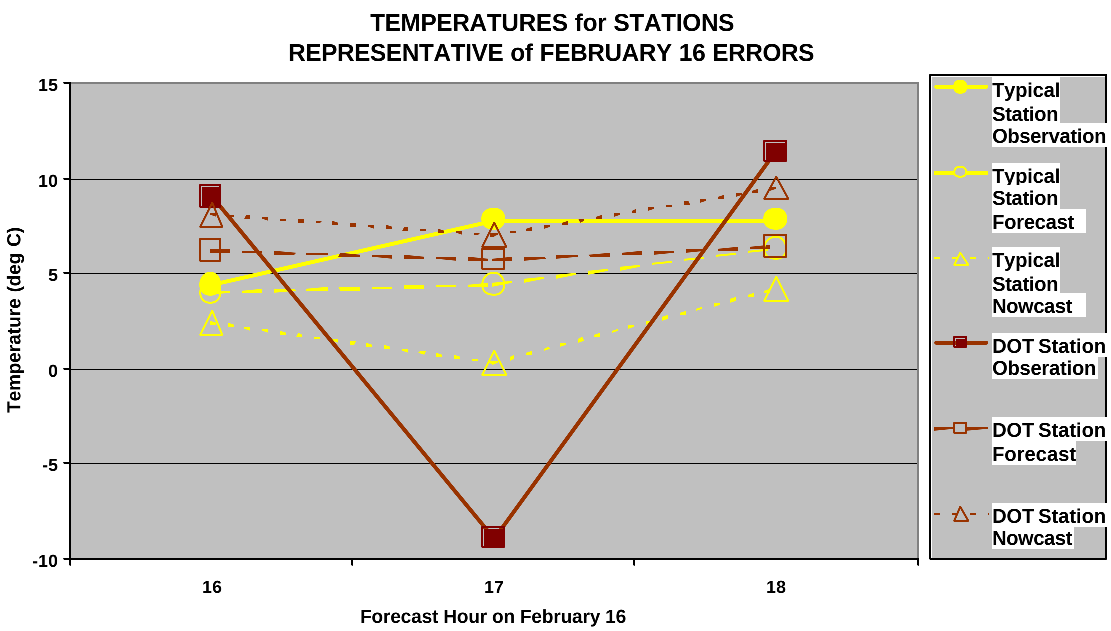
Transportation or DOT sites) including the erroneous low values are plotted in brown. Validation stations in the first group without unusual Hour 17 forecast errors are not shown. The input stations in blue letters did not report. Those in green letters reported observations with no anomalies in Hour 17. One input station (CRL in yellow text) reflected the "typical" group 2 trend of higher-than-expected warming between Hours 16 and 17. One input station (UT7 in brown text) included the "DOT" reported temperature as being approximately 15 °C lower than the previous or following hours' reported temperatures.

Specifically, this chart depicts the observed temperatures at the typical input station CRL and the DOT input station UT7. The forecast values for these stations are plotted as open symbols connected by dashed lines.



The temperature forecast for CRL is too low, but does include appropriate daytime warming between Hour 16 and Hour 18. Since this warming actually occurs by Hour 17, the errors are greatest at that time. The temperature drop for UT7 at Hour 17 is certainly not realistic, but the accuracy statistics are based on the values reported, so these purported forecast errors contributed significantly to the Hour 17 average error amounts. The archived data for UT7 and other Utah DOT stations do not retain any drop in temperature observations at Hour 17, but the corrected temperatures were not used in this trial.

The question now is, what do the **Nowcasters** do with this temperature prediction? This chart shows the failure to rely heavily on the necessary correction indicated by CRL at Hour 17 at the majority of stations, which would have brought the nowcast temperature much closer to the observed temperature at these sites.



This did not occur, and the **Nowcasters** generally predicted temperatures even lower at Hour 17 than the *Forecasters*, leading to greater errors probably due to the misleading input from UT7. Other input stations seem to have been relied on more heavily for the DOT station nowcasts, since at least their temperatures were appropriately higher than forecast values, while retaining a dip at Hour 17.

INSTALLMENT 6: *February Recap*

The February results include 24 days. The **Nowcasters** still come out ahead in the quest to accurately predict temperature and relative humidity, but by smaller margins than in the January trials. The wind speed category finishes this month in a tie, while the *Forecasters* continue to exhibit a slight advantage in wind direction. The absolute error amounts don't contain discernable trends associated with the time of day. The temperature bias forecast and nowcast lines plotted by forecast hour are fairly parallel, separated by about 1 °C. Most times include a small negative bias in the nowcast temperatures and a positive bias near 1 °C in the forecast temperatures. At intervals when the nowcast contains a greater negative bias of -0.5 to -1.0 °C, the forecast contains a very small positive bias (including Hours 1, 16 and 24.) The biases in relative humidity are slightly positive in the initial hours and become slightly negative in hours 7 through 16 for both the nowcasts and forecasts. In hours 17 through 23 they diverge, with the nowcast containing a small positive bias and the forecast a somewhat larger negative bias. The wind speed error hourly trends are similar to those seen in January, with predicted wind speeds slightly high during the night and morning hours and slightly low during the afternoon.

The following table provides the scores for the month of February.

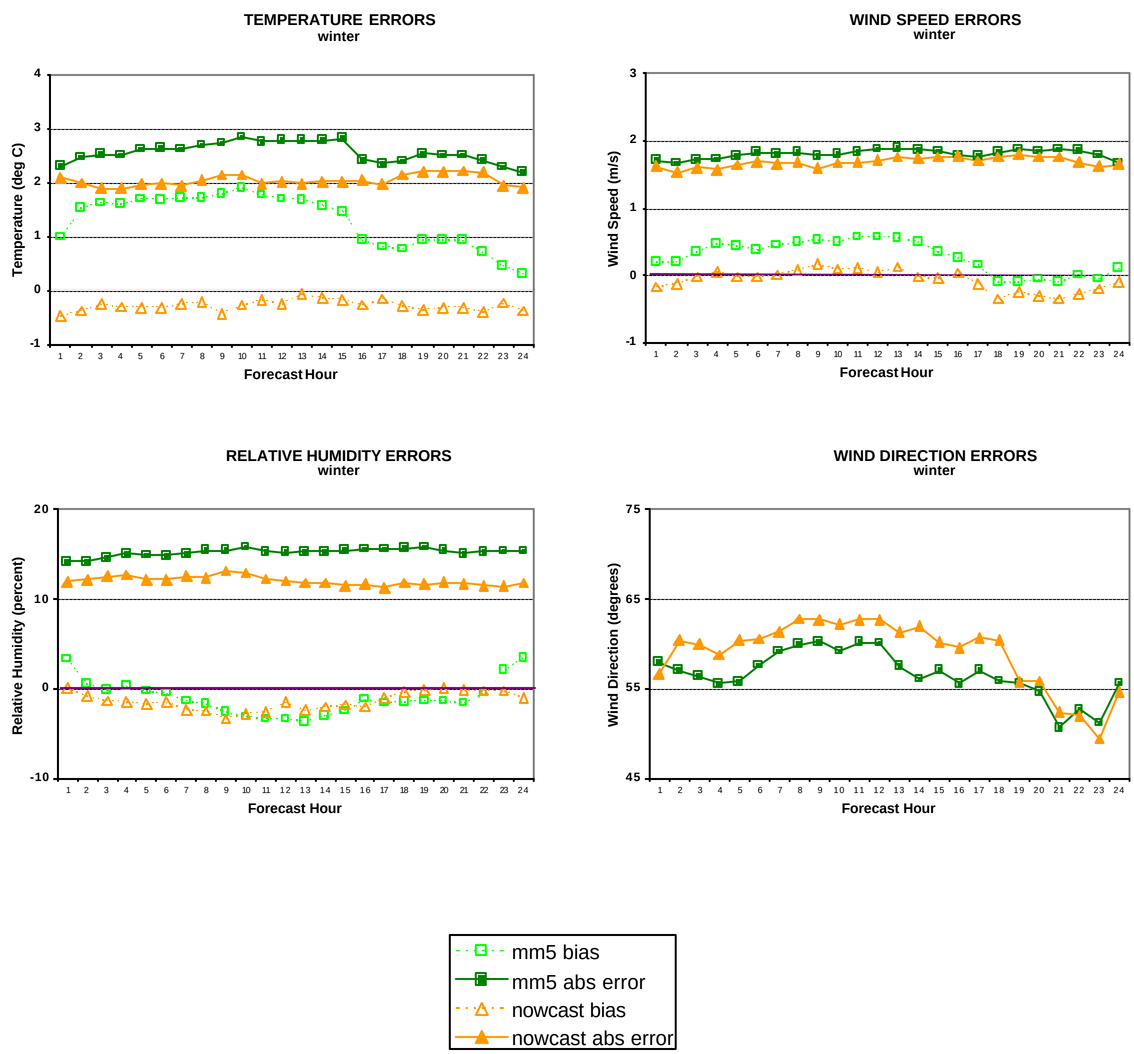
		Forecasters	Nowcasters	ADVANTAGE *month 3*
TEMP °C	*mean error*	0.9	-0.4	**Nowcasters** *by 0.5*
	abs error	2.4	2.1	**Nowcasters** *by 0.3*
RH %	*mean error*	-1.5	0.5	**Nowcasters** *by 1.0*
	abs error	14.7	11.2	**Nowcasters** *by 3.5*
WIND SPEED (m/s)	*mean error*	0.1	-0.1	***Tie***
	abs error	1.8	1.7	**Nowcasters** *by 0.1*
WIND DIR (deg)	*abs error*	51.7	52.8	Forecasters *by 1.1*

SERIES FINALE: *The Winners*

We've seen some erratic results in the individual days or stations highlighted in the preceding installments. However, by the time we consider the great volume of data based on all 50 days with 24 hourly predictions each day and usually 50-60 validation stations each hour, we have a pretty reliable picture of the capabilities of the competing Forecasters and **Nowcasters**.

Considering the difficulty of forecasting for such a complex area, both groups performed reasonably well overall. However, the Army desires more accurate predictions of each of the parameters involved than the average accuracies obtained during these winter days in Utah.

The following charts summarize the temperature, relative humidity, wind speed, and wind direction errors by the forecast hour. Recall that forecast hour 1 is based on a time of 01 GMT, which is 6 p.m. local or Mountain Standard Time in Utah.



Since the nowcast takes advantage of each hour's observation, we wouldn't necessarily expect any particular hour to show better results. However, it is interesting to note that the forecast errors do not grow as the forecast goes out in time. Surprisingly, the temperature bias and wind direction errors actually are somewhat lower late in the forecast period. Since the forecast hours only cover one diurnal cycle it's possible that the afternoon hours are less variable and compensate for decreasing forecast skill with time. It's also possible that the boundary conditions provide sufficient accuracy that the MM5 inner nest does not appreciably lose any forecast skill over 24 hours.

The greatest discrepancy between the *Forecasters* and the **Nowcasters** shows up in the temperature bias, where the nowcast contains a significantly smaller bias. The nowcast absolute errors are consistently smaller than the forecast errors throughout the temperature, relative humidity, and wind speed hourly plots. The improvements are sometimes small, however, particularly in the wind speeds. The forecasted wind direction is usually more accurate than the nowcast.

The following table provides the scores for all 50 days of the winter episode.

		Forecasters	**Nowcasters**	ADVANTAGE *winter*
TEMP °C	*mean error*	1.3	-0.3	**Nowcasters** *by 1.0*
	abs error	2.5	2.0	**Nowcasters** *by 0.5*
RH %	*mean error*	-1.0	-1.4	*Forecasters* *by 0.4*
	abs error	15.2	12.1	**Nowcasters** *by 3.1*
WIND SPEED (m/s)	*mean error*	0.3	-0.0	**Nowcasters** *by 0.3*
	abs error	1.8	1.7	**Nowcasters** *by 0.1*
WIND DIR (deg)	*abs error*	50.6	52.5	*Forecasters* *by 1.9*

Considering everything, it is clear that the winners are

WHAT THE CRITICS SAY: *Lessons Learned*

Although this series is replete with gratuitous stats, it provides a couple of lessons that earn it a thumbs up.

Future episodes should incorporate these lessons to provide more realistic results.

Lessons Learned

- A timely nowcast using surface observations from the area of interest can provide better weather intelligence on the battlefield.

- Additional work needs to be done on the nowcast methodology to obtain the accuracy desired by the Army.

- Incorporating additional logic and error checking can guide the nowcast to use the most beneficial observations for correcting the forecast.

  - ✓ consider the elevation of the input stations

  - ✓ perform error checks for observations outside allowable maximum and minimum values for each parameter

  - ✓ perform error checks for observations containing large discrepancies between adjacent reporting times or other nearby stations' observations

- Future users will want nowcasts at heights above the surface.

STAY TUNED FOR FUTURE EPISODES

CREDITS

CAST OF CHARACTERS

GFS (former screen name AVN)	National Center for Environmental Prediction Global Forecast System. Since April 2002, the NCEP MRF and AVN forecast models have been combined into a single system and renamed the Global Forecast System (GFS). http://www.emc.ncep.noaa.gov/modelinfo/index.html
MM5	Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model version 5 http://www.mmm.ucar.edu/mm5/
NOWCAST	Successive corrections applied to the MM5 output, most recently appearing in conjunction with the Battlescale Forecast Model (BFM) in Utah and Oklahoma! Sauter, B.; Henmi, T.: *Short-Term Battlescale Forecast Model Performance Incorporating Utah Mesonet Stations.* Technical Report ARL-TR-2810, US Army Research Laboratory, WSMR, NM, Feb 2003. Sauter, B.; Henmi, T.; Dumais,R.: Comparing Nowcasting Methods Using Oklahoma Mesonet Data. *Proceedings of the Battlespace Atmospheric and Cloud Impacts on Military Operation (BACIMO) Conference 2001, July 2001.*

INPUT STATIONS	General Area	Station ID	Elevation (m)
	Idaho	MALI	1380
	Wyoming	KEM	2100
	Northern Utah	LGP	2730
		LMS	1290
		SBE	1920
		UT1	2110
		LMR	1540
	Salt Lake City	SNZ	1450
		HQ2	1270
		FWP	2800
		ALT	3180
		UT7	1430
		SND	2510
	Dugway Proving Ground	ARAU1	1530
		CRL	1570
		VRN	1690
	Central Utah	ELMO	1700
		LITW	2600

SPONSORS

KARL

Western affiliate of the US Army Research Laboratory,
White Sands Missile Range, NM
Barb Sauter, AMSRL-CI-EB, (505) 678-2840; bsauter@arl.army.mil
http://www.arl.army.mil

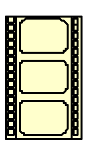
AHPCRC

US Army High Performance Computing Resource Center,
Minneapolis, MN
http://www.ahpcrc.org

UTAH MESOWEST

University of Utah, Utah MesoWest Cooperative
Horel, J.; Splitt, M.; Dunn, L.; Pechmann, J.; White, B.; Ciliberti, C.; Lazarus, S.; Slemmer, J.; Zaff, D.; Burks, J.: MESOWEST: Cooperative Mesonets in the Western United States. *Bulletin of the American Meteorological Society 2002, 83, 211-225.*
http://www.met.utah.edu/jhorel/html/mesonet/

Data flags exist to highlight observations outside allowable limits, but they were not used in the data files transferred from the University of Utah to the Army Research Laboratory for this project.



No models were injured
in the creation of this production.